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1 **Grapes and vines of the Phoenicians: morphometric analyses of pips from**
2 **modern varieties and Iron Age archaeological sites in the Western**
3 **Mediterranean**

4 Claudia Moricca^{1,2*}, Laurent Bouby³, Vincent Bonhomme³, Sarah Ivorra³, Guillem Pérez-Jordà⁴,
5 Lorenzo Nigro⁵, Federica Spagnoli⁵, Leonor Peña-Chocarro⁶, Peter van Dommelen⁷, Laura Sadori²

6 ¹ Department of Earth Sciences, Sapienza University of Rome, Piazzale Aldo Moro 5, 00185 Roma, Italy;
7 claudia.moricca@uniroma1.it

8 ² Department of Environmental Biology, Sapienza University of Rome, Piazzale Aldo Moro 5, 00185
9 Roma, Italy

10 ³ ISEM (UMR 5554), Univ Montpellier, CNRS, IRD, EPHE, Montpellier, France

11 ⁴ GRAM-GIUV2015-222, Department de Prehistòria, Arqueologia i Història Antiga, Universitat de
12 València, Avda. Blasco Ibañez 28, 46010, València, Spain

13 ⁵ Department “Italian Institute of Oriental Studies – ISO”, Sapienza University of Rome, Circonvallazione
14 Tiburtina 4, 00185 Roma, Italy

15 ⁶ GI Paleoeconomía y Subsistencia de las Sociedades Preindustriales, Instituto de Historia (CSIC). Albasanz
16 26-28, E-28030 Madrid, Spain

17 ⁷ Joukowsky Institute for Archaeology and the Ancient World, Brown University, Providence, RI, USA

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31 Abstract

32 The present study aims to contribute to the investigation of the role of Phoenicians in the spreading
33 and trade of the grapevine through the morphometric analysis of grape pips. Waterlogged and
34 charred samples were selected from three Iron Age sites in the Western Mediterranean: Motya
35 (Sicily, Italy), Nuraghe S'Urachi (Sardinia, Italy) and Huelva (Andalusia, Spain). While only
36 Motya is a Phoenician foundation, all three were nevertheless associated with Phoenician
37 expansion and cultural interaction. Ten cultivars from the "Vivaio Federico Paulsen" in Marsala
38 (western Sicily) were chosen as modern reference material.

39 The key challenge was the comparison of archaeological pips preserved through different
40 fossilization processes, which was overcome using two reference datasets of the same modern
41 cultivars, one uncharred and one charred.

42 Statistical analyses of pip outlines show that archaeological remains from these sites is
43 morphologically comparable to that of modern varieties, suggesting that the archaeological finds
44 represent domesticated grapevines.

45 PCA analyses allowed an inter-site comparison, showing that samples from the three sites are
46 clearly distinguishable based on their morphology. This indicates the use of different varieties
47 which may be due to different factors.

48 Our analysis represents a first step towards a better understanding of diachronic and synchronic
49 relationship between vines grown in the ancient West Mediterranean, which could be expanded by
50 analysing grape pips from more contexts and more sites, compared against a wider selection of
51 modern cultivars.

52 **Keywords:** Phoenicians, viticulture, morphometry, Western Mediterranean, experimental
53 charring

54 1. Introduction

55 This study aims at better understanding the role of Phoenicians in the spreading and trade of the
56 grapevine in the Western Mediterranean through the morphometric analysis of grape pips from
57 three Western Mediterranean sites dated to between the 9th and the 6th centuries B.C.

58 The grapevine (*Vitis vinifera* L.) is one of the most important fruit crops of the past and present
59 world, both economically and culturally. The wild and cultivated forms, respectively *Vitis vinifera*
60 L. subsp. *sylvestris* (C.C. Gmel.) Hegi and *V. vinifera* L. subsp. *vinifera*, differ by an array of traits,
61 including their reproductive biology. Wild grapevine is dioecious and is cross-pollinated, while
62 domesticated grapes are in most cases hermaphrodite and capable of self-pollination (Negi and
63 Olmo, 1966; This et al., 2006). Domestication has also resulted in an increase in berry size and
64 sugar content, which are both factors that play a key role in fermentation (Miller, 2008; Bouby et
65 al., 2013). Differences can moreover be observed in the shape of its seeds, with wild pips being
66 "small, robust, with a rounded outline, or cordate, with short stalks [...] almost flat ventrally with
67 sharp angles and a strongly developed chalaza", in contrast with cultivated ones that are large,

68 elongated, oval or pyriform, with a longer stalk, more rounded ventrally and less sharply sculptured
69 (Mangafa and Kotsakis, 1996, p. 409; Levadoux, 1956; Jacquat and Martinoli, 1999).

70

71 The origins of wine production have been traced back to the Caucasus in the 7th-6th millennia
72 (McGovern et al., 2017). It is unknown if these first wines were made from wild or cultivated
73 grapes (Bouby et al., 2021). Nonetheless, all evidence indicates that domesticated grapes also
74 originated there (e.g. Myles et al., 2011). Grapevine was cultivated, and probably domesticated, in
75 South West Asia by at least the 4th millennium BC (e.g. Miller, 2008; Fuller and Stevens, 2019).
76 Recent studies based on morphometric analyses of grape pips also suggest an early local
77 domestication in Greece that goes back to the Neolithic (Pagnoux et al., 2021). It is believed that
78 new domesticated varieties were subsequently introduced in Greece during the Late Bronze Age,
79 possibly through increased exchanges and trade with the Near East.

80 The importance of fruit trees in past societies is greatly correlated to their role as a source of food
81 products with significant economic value, such as dried fruits, oil and wine. At least in some cases
82 their cultivation was initially based on reproduction by seed, which implies a great deal of
83 uncertainty because of the heterozygosity inherent in many fruit species, which means that
84 seedlings often give rise to offspring that are very different from the parents (Bouby and Ruas,
85 2014). The switch to vegetative propagation through cuttings, marcotting and grafting is
86 accordingly widely seen as a milestone in the domestication of fruit trees, as this allows the
87 propagation of cultivars that are basically clones (Bouby and Ruas, 2014).

88

89 Grassi et al. (2003), Imazio et al. (2004), Arroyo-García et al. (2006) and more recently Riaz et al.
90 (2008) have performed simple sequence repeats (SSR) analyses on wild and cultivated grapevines.
91 Their results suggest the presence of at least two separate grape domestication events: one in
92 Transcaucasia and another one in Western Europe, possibly in Spain and Sardinia. More recently,
93 De Michele et al. (2019) considered the hypothesis of a domestication centre and/or local
94 introgression in Sicily, given the close relation between Sicilian wild populations and local
95 cultivated germplasm. Scienza (2008) and Forni (2012) describe several centers of
96 “accumulation”, areas near ports located on major commercial routes, where many varieties were
97 gathered over the centuries due to frequent and intensive contacts and interactions. Some of these
98 areas have been identified as key centers of diversity. Distinct groups of cultivated grapevines
99 were proposed by Negru, who identified three *proles*: a *proles pontica* between Georgia and Asia
100 Minor and in the Balkans, a *proles occidentalis* in Italy, France, the Iberian Peninsula, and
101 Germany, and a *proles orientalis* in Central Asia, Persia, Armenia and Afganistan (Dalmasso,
102 1961). These groups match recent genetic evidence (eg. Bacilieri et al., 2013).

103 Riaz et al. (2018) suggest that cultivars from the *proles pontica* were introduced to Western
104 Europe, because the wild grapes of Georgia – identified as an ancient centre of grapevine
105 domestication – are closely related to Caucasian cultivated grapes (*proles pontica*) and the Western
106 Mediterranean ones (*proles occidentalis*).

107 Today, domesticated grape diversity is the result of millennia of human selection and diffusion.
108 Ancient civilizations such as the Assyrians, Phoenicians, Greeks, Etruscans and Romans spread
109 viticulture first across the Mediterranean basin, and later also into more temperate regions
110 (McGovern, 2003). In the Western Mediterranean, there is an increasingly clear link between the
111 Phoenician presence and the development of viticulture (Botto, 2013), as may be seen from both
112 the archaeobotanical record (Buxó 2008; Pérez-Jordà et al., 2017; 2021; Uccesu et al., 2015), and
113 other elements in the archaeological record such as wine presses (Gómez Bellard et al., 1993) or
114 evidence of trench agricultural systems (Vera Rodríguez and Echevarría Sánchez 2013). Evidence
115 of *Vitis vinifera* in Phoenician sites is also found in association with animal bones (e.g. Moricca et
116 al., 2020; Portas et al., 2015), as it is believed that the waste from winemaking was used by
117 Phoenicians for meat preservation thanks to the antioxidant capacity of grapes (Sabato et al., 2019).
118 Morphometry, the statistical analysis of form and its (co)variation (Rohlf and Bookstein, 1990),
119 has played a key role in the study of grape pips from archaeological contexts since the early 20th
120 century to distinguish between wild and domesticated seeds (Stummer, 1911; Mangafa and
121 Kotsakis, 1996). The approach was initially mainly based on measuring the length and breadth of
122 the whole pip but it has developed to include multiple parameters, such as the length of the stalk
123 or the position of the chalaza (Rivera Núñez et al., 2007); more recently, it has embraced geometric
124 morphometrics and, in particular, outline analysis (Terral et al., 2010). Although only genetic
125 analyses can demonstrate a direct connection between modern cultivars and archaeobotanical
126 specimens (Guasch-Jané, 2019), geometric morphometric analyses are useful in archaeobotany,
127 where shape is often the only remaining datum (Portillo et al., 2020). Since most of the surviving
128 plant remains are usually seeds, outline analyses that do not require landmarks are particularly
129 suitable and have been successfully used in numerous studies (eg. Ekhvaia and Akhalkatsi, 2010;
130 Terral et al., 2010; Orrù et al., 2013; Ros et al., 2014; Pagnoux et al., 2015; Sabato et al., 2015a;
131 Bonhomme et al., 2017; Bourgeon et al., 2018; Boso et al., 2020). Desiccated remains, whose
132 shape was not modified by (sub)fossilization, have proven to be the most suitable material for
133 morphometric analysis, followed by waterlogged ones (Bouby et al., 2013). An additional
134 advantage that these categories carry is the possibility to perform DNA analyses, which can serve
135 as a complementary tool (Bacilieri et al., 2017).

136 The study of charred grape pips is more challenging, as the (sub)fossilization results in a notable
137 degree of deformation, in particular a swelling of the seed, which mostly occurs on the ventral side
138 and which is best observed on the lateral outline (Smith and Jones, 1990; Bouby et al., 2018). This
139 kind of deformation skews the identification of pips, moving them towards the wild morphotype.
140 Despite the distortion of charred botanical remains, differences in seed shape may remain
141 informative. Attempts to perform morphometric analyses on charred grape pips have been recently
142 undertaken by Uccesu et al. (2016) and Bouby et al. (2018), who both concluded that it is possible
143 to distinguish between wild and domesticated pips, even if they are charred. Bouby et al. (2018)
144 have moreover shown that if charring occurred at a temperature of 250°C or less, wild and
145 domesticated pips may not only be correctly distinguished from each other, but it is also possible
146 to identify correctly a high percentage of domesticated pips. Charring at higher temperatures

147 increases the classification error, which means that cultivar classification may only use modern
148 pips charred at lower temperatures and archaeological remains exposed to charring at low
149 temperatures. Since it is hard to reconstruct the temperature that formed the archaeobotanical
150 material, it is necessary to consider only large groups of very well preserved pips. In contrast,
151 inflated specimens (indicative of higher temperatures) should only be considered for distinguishing
152 wild from domesticated pips (Bouby et al., 2018). This paper compares, for the first time, grape
153 pips collected from different sites with Phoenician connections to explore Phoenician interactions
154 with plants and food and the role of commercial routes and trade goods. Were Phoenicians
155 responsible for the spread of viticulture to the western Mediterranean? Or did they exploit and
156 possibly domesticate wild grapes? Are modern cultivars a result of Phoenician influence?

157

158 **1.1. Study sites**

159 The present study focuses on the analysis of finds from three sites related to the Phoenician-Punic
160 diaspora: Motya, Huelva and Nuraghe S'Urachi, which are respectively situated in Sicily (Italy),
161 the Iberian Peninsula and Sardinia (Italy; Fig. 1). Motya was a Phoenician foundation, but both
162 S'Urachi and Huelva were indigenous settlements already in existence before Phoenicians arrived
163 in Sardinia and southern Spain.

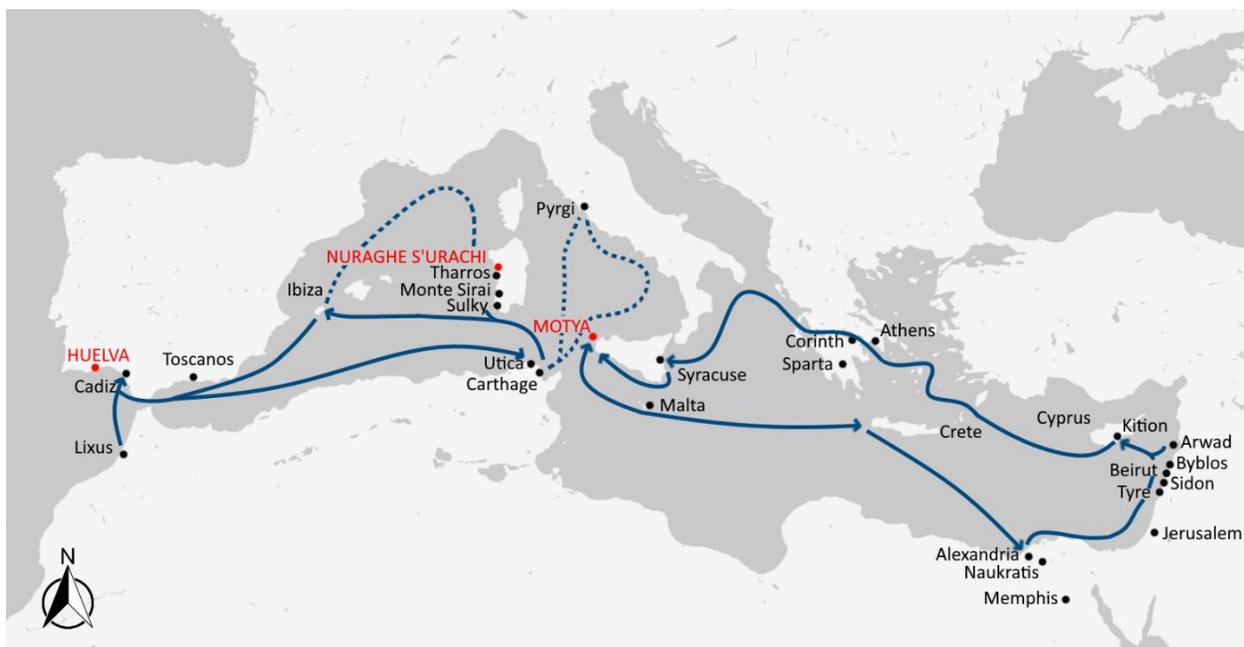
164 Phoenicians and their material culture travelled the length and breadth of the Mediterranean in the
165 first half of the 1st millennium BC (Aubet Semmler, 2001; López-Ruiz and Doak, 2019). Their
166 expansion from modern Lebanon towards the Western Mediterranean involved the major islands
167 and many mainland coastal areas of the Mediterranean, such as Crete, Sicily, Sardinia, Andalusia
168 and coastal North Africa. In all these areas, commercial and agricultural settlements were newly
169 established or created in association with existing indigenous ones, and the relations between
170 Phoenicians and local communities became a key aspect of the economic and social transformation
171 of these regions.

172 While only Motya is a Phoenician foundation, all the three sites studied were nevertheless firmly
173 associated with Phoenician expansion and cultural interaction.

174 Motya is a small island of about 45 ha situated in a sheltered lagoon on the Sicilian west coast,
175 where it had offered an ideal “stop-over point” on trade routes into the West Mediterranean,
176 including Sardinia, since the second millennium BC. The establishment of a permanent settlement
177 in the 8th century BC enabled the Phoenicians to consolidate their trade with the indigenous
178 inhabitants of western Sicily (Nigro and Spagnoli, 2017; Nigro, 2018). The island had previously
179 been inhabited by local Sicilian communities (Nigro, 2018).

180 Nuraghe S'Urachi is situated on the central west coast of Sardinia, on the northern shores of the
181 Gulf of Oristano. The nuraghe itself was first built sometime in the Middle Bronze Age or mid-2nd
182 millennium BC and remained continuously occupied well into the 1st millennium BC. From around
183 the turn of the 8th-7th century, Phoenician material culture was imported in increasingly abundant
184 quantities and subsequently locally produced, suggesting a stable presence of Phoenicians (Stiglitz,
185 2007; van Dommelen et al., 2020).

186 Situated in the coastal wetlands created by two rivers flowing into the Atlantic, the site of Huelva
 187 was likewise an indigenous settlement, where Phoenician material culture was imported as early
 188 as the 9th century BC. It offered access to an important mining district in the interior, which enabled
 189 its inhabitants to establish connections across both the Atlantic and the Mediterranean (Ruiz-
 190 Gálvez Priego 1986; 2014). A small quantity of Sardinian pottery amidst a rich variety of
 191 Phoenician and other imports shows the involvement of both indigenous communities in
 192 Phoenician commercial networks (Gonzales de Canales et al., 2006).



193
 194 *Figure 1.* Map of the Mediterranean with the sites of Motya (37°52'05"N, 12°28'10"E), S'Urachi (40°00'56"N,
 195 8°34'57"E), and Huelva (37°14'53"N, 6°56'58"W) along the Phoenician trade routes.

196 2. Materials and Methods

197 2.1. Modern material

198 Ten cultivars collected from the “Vivaio Federico Paulsen: Centro Regionale per la Conservazione
 199 della Biodiversità Agraria” in Marsala (TP, western Sicily) were selected as modern reference
 200 material (<http://vivaiopaulsen.it>). The choice of cultivars was based on their geographic origin,
 201 with three cultivars regarded as native to Georgia (“Chichvi”, “Ogialesci” and “Zerdagi”), five to
 202 Sicily (“Albanello”, “Catarratto”, “Inzolia”, “Perricone” and “Vitarolo”) and one to mainland
 203 Italy (“Coda di Volpe” - Tab. 1; Ansaldi et al., 2014, Galet, 2000). Sicilian varieties were chosen
 204 because they are assumed to be local, as they are attested in Sicilian writings since the 16th century
 205 (Ansaldi et al., 2014). They may therefore be related to archaeological samples. The present study
 206 is moreover the first one to use a reference collection focused on Sicilian cultivars. The origin of
 207 “Zibibbo”, also known as “Muscat of Alexandria”, is debated. It has a long history of cultivation
 208 in Sicily, presumably starting with the Arabic domination of the Island (ca. 9th century AD), even
 209 if it only first described as a cultivar in 1696 by Francesco Cupani (De Lorenzis et al., 2015).

210 Although many cultivars have both black and white mutants (e.g. “Pinot”), we have maintained a
 211 balance in our sample between black and white grapes. 30 grape pips of each cultivar have been
 212 sampled for the present study, and each pip was given a unique identification code in order to
 213 compare its morphology before and after charring.

Abbreviation	Cultivar	Origin	Berry color	Number of pips
Alban	“Albanello”	Sicily	White	30
Catar	“Catarratto”	Sicily	White	30
Chicv	“Chichvi”	Georgia	White	30
Codad	“Coda di Volpe”	Italy	White	30
Inzol	“Inzolia”	Sicily	Black	30
Ogial	“Ogialesci”	Georgia	Black	30
Perri	“Perricone”	Sicily	Black	30
Vitra	“Vitrarolo”	Sicily	Black	30
Zerda	“Zerdagi”	Georgia	Black	30
Zibib	“Zibibbo”	Uncertain	White	30

214
 215 *Table 1.* Modern cultivars selected for the reference collection

217 2.2. Charring conditions

218 Experimental charring was performed on the selected pips in order to train identification models
 219 with pips representative of well-preserved archaeobotanical material. Charring conditions were
 220 established following the studies realized by Uccesu et al. (2016) and Bouby et al. (2018), which
 221 evaluated the most suitable conditions of experimental charring for morphometric studies. They
 222 respectively defined temperature ranges of 240-310°C and 250-450°C, below which charring
 223 resulted in heterogeneous carbonization and above which the pips disintegrated. Oxygen
 224 availability and duration of heating had a smaller impact on pip deformation, although it seemed
 225 slightly more accentuated under oxidizing conditions. Complete charring of the reference
 226 assemblages occurred already after 20 minutes. Bouby et al. (2018) concluded that only pips
 227 charred at a low temperature should be used for identification at the cultivar level, as charring at
 228 250°C allowed not only to distinguish correctly between wild and domesticated pips, but also to
 229 identify accurately specific varieties.

230 Each of the selected pips, which had previously been given a unique identification code, was
 231 wrapped in two layers of aluminum foil in order to re-create reducing conditions, and to simulate
 232 the taphonomic factors which resulted in the creation of the archaeological assemblage. The pips
 233 were placed in a Thermolyne 48000 furnace at ambient temperature, the temperature was set at
 234 250°C and the furnace was turned on. After 90 minutes the sample tray was removed from the
 235 oven.

236 2.3. Archaeological material

237 Archaeological grape pips were collected from the western Mediterranean sites of Motya, Nuraghe
 238 S’Urachi and Huelva. The archaeological material from Motya consisted of 189 grape pips
 239 deriving from an 8th-6th century BC refuse pit, which had been preserved by carbonization and
 240 retrieved using the bucket floatation technique. The grape seeds come from six stratigraphic units
 241 interpreted as four depositional events (Table 2; Moricca et al., 2021). Few pedicels were found
 242 compared to the number of grape seeds. This is coherent with wine-making refuse as studied by
 243 Margaritis and Jones (2006).

Filling layer (FL)	Stratigraphic unit (US)	Chronology
I-III	1112 2268	End of 7 th – mid 6 th century BC
IV	1406 1407	Mid-7 th century BC
V	1492	End of 8 th – first half of the 7 th century BC
VI	7234	Mid-second half of the 8 th century BC

244
 245 *Table 2. Stratigraphy of the Motya deposit (modified after Moricca et al., 2021).*

246
 247 The material from the sites of S’Urachi and Huelva was by contrast preserved by waterlogging.
 248 The 179 grape pips from S’Urachi come from the fill of a trench that was backfilled with rubbish
 249 from the early 7th century BC onwards, along with other fruits, cereals as well as large quantities
 250 of animal bones and pottery (Pérez-Jordà et al., 2020).
 251 The 253 pips from Huelva were recovered from a fill context that possibly represents waste
 252 dumped in a port area. The sediment was extracted mechanically but associated radiometric dates
 253 and archaeological evidence allow us to place it in the 9th-8th century BC (Pérez-Jordà et al., 2017).

254 **2.4. Morphometric analysis**

255 Modern (both pre- and post-charring) and archaeological grape pips were positioned on a blue
 256 background and photographed in dorsal and lateral position (Fig. 2) at a fixed magnification using
 257 an Olympus SZ-ET stereomicroscope and an Olympus DP 12 camera. These images were
 258 processed in order to obtain black masks on a white surface. Outlines coordinates (x; y) were
 259 extracted and 360 points, equally spaced along the curvilinear abscissa were sampled.
 260 Normalization of the outlines was carried out by centering, aligning them along their longest axis,
 261 scaling them using their centroid size, and by defining the first point right above the centroid
 262 (Bouby et al., 2018). Elliptic Fourier transform (EFT) approach (Kuhl and Giardina, 1982)
 263 subsequently enabled us to turn the shape into multivariate coefficients. EFT involves the
 264 decomposition of x- and y- coordinates as two harmonic sums of trigonometric functions
 265 (Bonhomme et al., 2014). The two views were treated separately, and their coefficients were later
 266 combined. In our case, seven harmonics were chosen for the two views, enough to gather 99% of
 267 the total harmonic power. Each harmonic corresponds to four coefficients, so EFT resulted in 56
 268 coefficients (2 views × 7 harmonics × 4 coefficients per harmonic), which weretreated as

269 quantitative variables. The Momocs package (Bonhomme et al., 2014; version 1.3.2 available at
270 <https://github.com/MomX/Momocs>) was used for morphometric analysis. All analyses were
271 performed in the R environment, version 4.0.2 (R Core Team, 2020).



272
273 *Figure 2.* Pip #4 from stratigraphic unit US 1492 (Motya) in dorsal and lateral views.
274

275 **2.5. Statistical analyses**

276 To begin with, shape variability of the modern charred and uncharred pips and the archaeological
277 seeds were assessed and compared at different levels using Principal Component Analyses (PCA).
278 Preliminary analyses were conducted to quantify any error related to the positioning of pips for
279 photographic documentation and their graphical elaboration. A PCA_{geo} (Fig. 3) on the matrices of
280 the EFT coefficients of modern uncharred pips was first calculated to characterize seed shape
281 variability at the cultivar level. A mean score was drawn up for each variety. The first two principal
282 components (PC 1 and PC 2) are shown in Figure 3, along with the corresponding morphological
283 space that illustrates the shape components captured by these PCs. Secondly, charred samples were
284 projected as supplementary observations in PCA_{geo} to visualize the effects of charring on pip shape
285 (PCA_{exper} ; Fig. 4). Here again, only average scores per variety are represented. Mean shapes for
286 modern pips were also calculated to visualize these changes (Fig. 5).

287 Regarding the archaeological pips, a PCA_{archeo} (Fig. 6) was carried out in order to compare the pips
288 from the sites of Motya, Nuraghe S'Urachi and Huelva. We used the first 12 PCs, that gather 95%
289 of the total variance to test for differences between assemblages using a permutational MANOVA
290 as implemented in the package 'vegan' (Oksanen et al., 2019). We then carried out two PCAs
291 (PCA_{water} and PCA_{char} ; Fig. 7 and 8) on modern material (uncharred and charred). The waterlogged

292 (Huelva and S'Urachi) and charred (Motya) archaeological pips were reprojected on these PCAs
293 as additional observations.

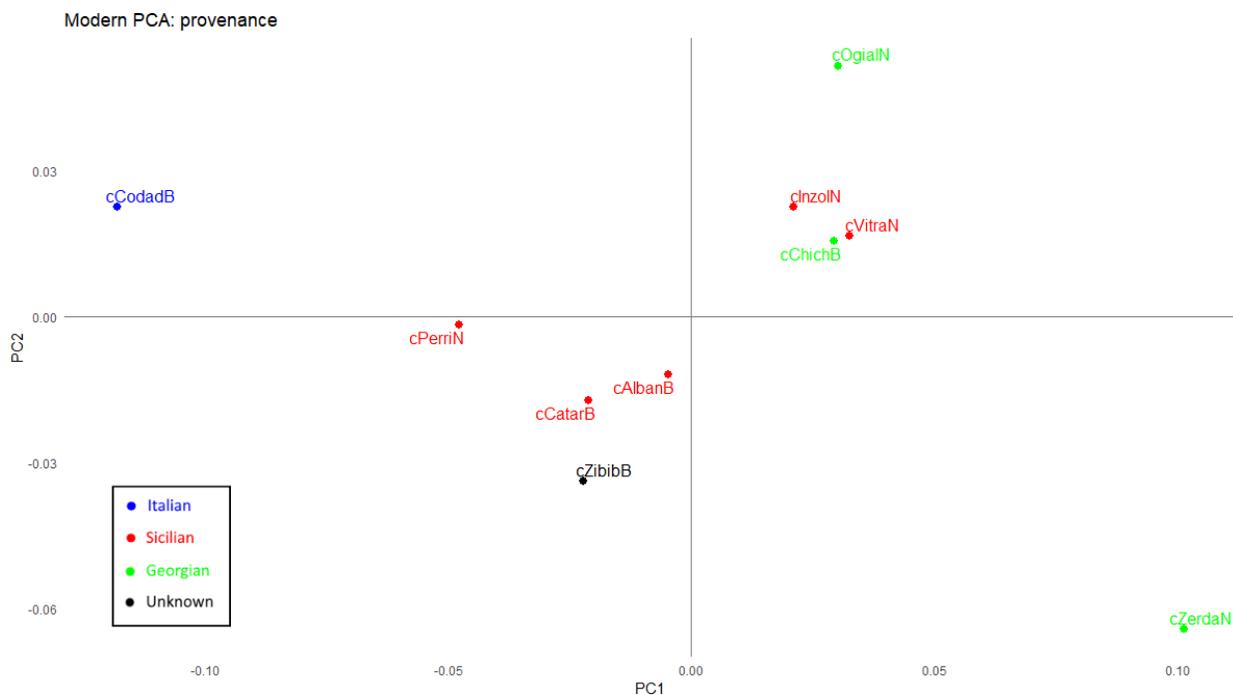
294

295 3. Results

296 The first two principal components (PCs) of the PCA performed on uncharred modern samples
297 (PCA_{geo}) explain 59.2% of the total variance (Fig. 3). PC1 (38.2%) distinguishes between roundish
298 pips with a short stalk, characterizing shapes close to the wild morphotype, and more elongated
299 pips with a longer stalk, typically associated with cultivated grapes. PC2 (21.0%) mostly captures
300 the straightness/curviness of the pip outline in lateral view.

301 3.1. Provenance of cultivars

302 The application of PCA_{geo} to modern materials makes it possible to highlight the differences in
303 seed shape between cultivars, which can be compared to the geographical origin of each cultivar
304 (Fig. 3).



305
306 *Figure 3. PCA on reference cultivars in association with their geographical origin (PCA_{geo}).*

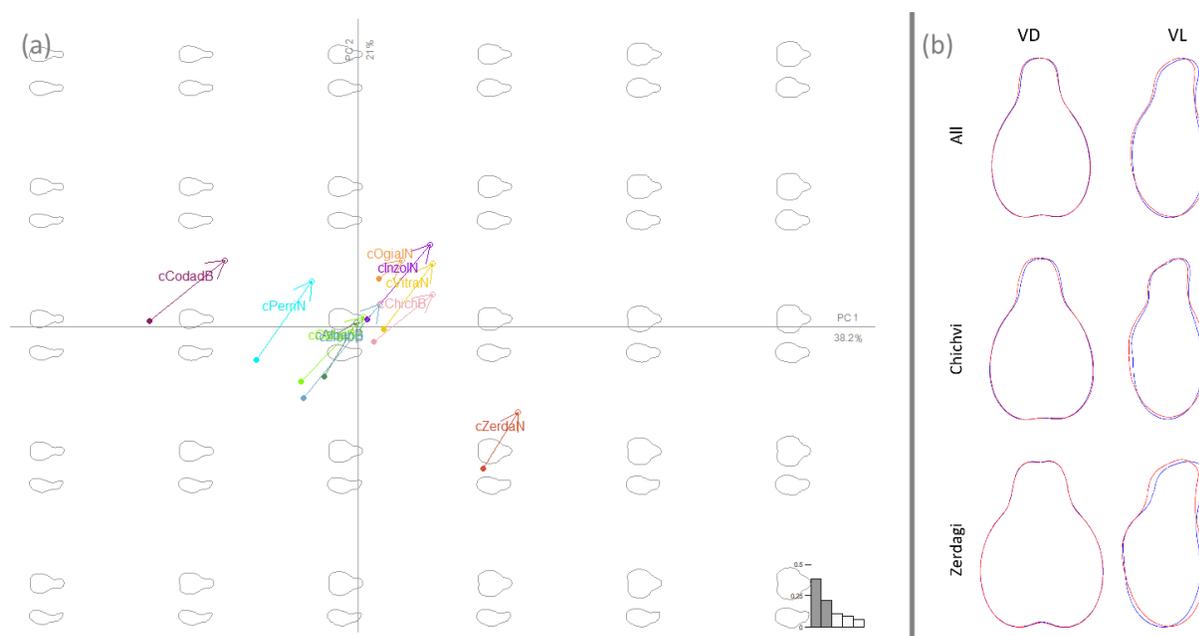
307

308 The center of the plot is occupied by the Sicilian cultivars, while the Georgian ones are shifted
309 towards the righthand side of the graph. Pips of the Georgian cultivars are broader and more
310 laterally curved than the Sicilian ones, which present a shape closer to that of wild plants. “Coda

311 di Volpe”, which is the only cultivar from the Italian mainland in the analysis, presents by contrast
 312 pips that are on average more elongated and straighter in the lateral outline.

313 3.2. Charring effect

314 PCA on reference materials has enabled us to describe the effects of experimental charring in terms
 315 of changes in pip shape (PCA_{exper} ; Fig. 4). This is reflected in a general inflation of the pip bodies,
 316 resulting in an overall plumpness (PC1) and a straightening of the lateral outline (PC2). All
 317 cultivars follow a similar pattern. The calculated mean shapes associated with the charring
 318 conditions (Fig. 5) show that charring mostly affects the lateral section, particularly on the ventral
 319 side with an inflation of the body and a change in inclination of the beak. The changes in the dorsal
 320 view are nevertheless much lower.



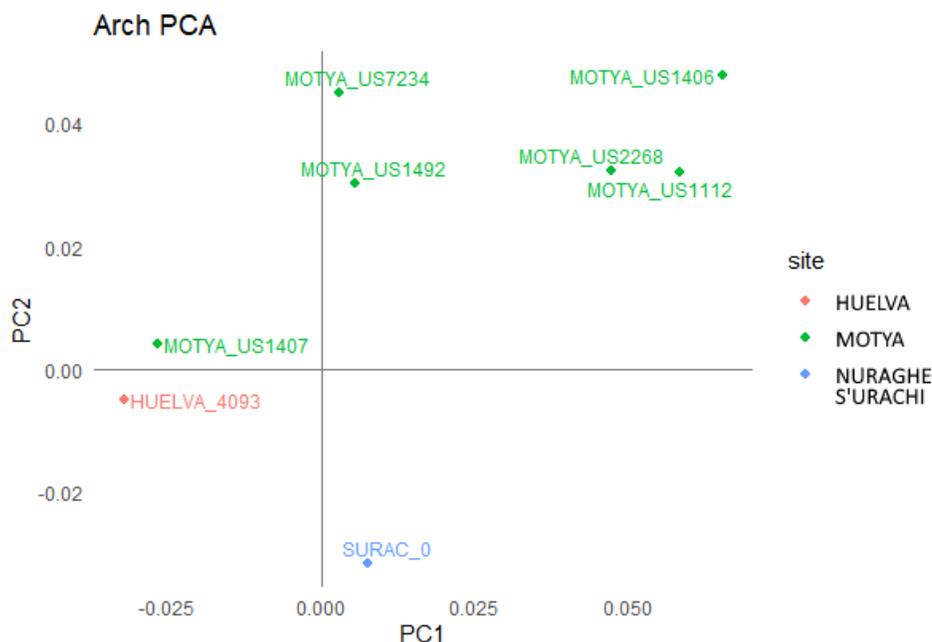
321
 322 *Figure 4.* The effects of charring on modern cultivars: a) PCA describing the effects of charring on modern cultivars
 323 (PCA_{exper}); b) mean shapes of all pips, Chichvi pips and Zerdagi, dorsal (left) and lateral (right) outlines. Blue line
 324 for uncharred pips, red for charred ones.

325 326 3.3. Comparison of archaeological samples

327 A PCA of all the archaeological samples was also carried out (PCA_{archeo} ; Fig. 6). In PCA_{archeo} , the
 328 first two PCs explain 59.6% of the total variance. PC1 (40.9% of variance) distinguishes roundish
 329 pips with a short stalk from the more elongated ones, with a longer stalk, while PC2 (18.7% of
 330 variance) is correlated with the curvature of the lateral outline.

331 While some differences can be seen along PC1, with pips from Motya’s stratigraphic units 1112,
 332 1406 and 2268 being rounder than the others, most differences can be observed along PC2.
 333 Waterlogged pips, particularly from S’Urachi are characterized by a more curved lateral outline,

334 while pips from the Motya deposit have a straighter lateral outline. This is coherent with the results
 335 of the previous analyses, as PC2 is mostly explained by charring. Pips from Huelva and Motya’s
 336 US 1407 are very similar, as they are the most elongated ones among the studied pips; they also
 337 have a similar curvature in the lateral outline. While looking specifically at the waterlogged
 338 assemblages, it is possible to see that pips from S’Urachi are the broadest. This analysis does not,
 339 however, take into consideration the effect of charring, which our experiments have shown to
 340 cause an inflation of the pip body.



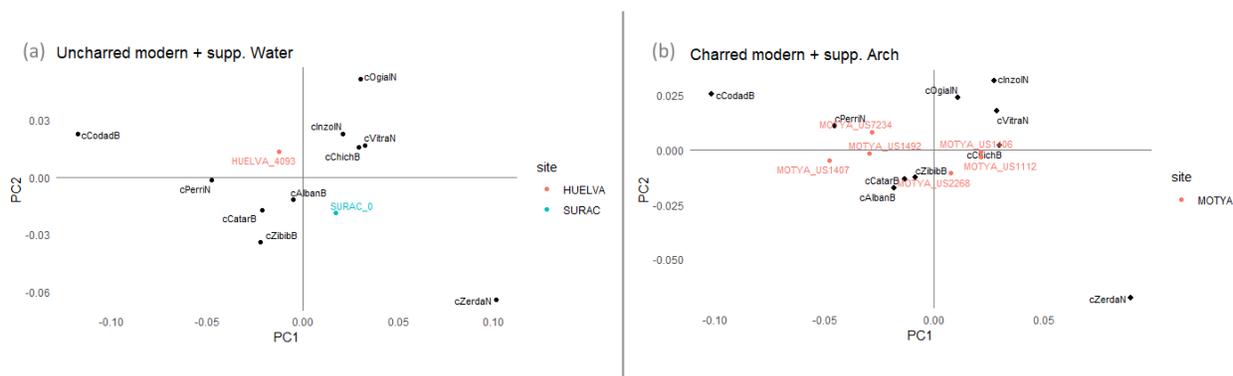
341 Figure 5.
 342 PCA of archaeological samples (PCA_{archeo}).

343
 344 For this reason, separate PCA analyses were also performed on the waterlogged (Supplementary
 345 Material 1) and charred archaeological pips (Supplementary Material 2). These analyses showed
 346 results coherent with those obtained in PCA_{archeo}.

347 Archaeological waterlogged samples were later projected on PCA_{geo}, previously obtained for
 348 modern uncharred pips (Fig. 7). PCA_{water} allows morphological comparison of the pips from
 349 Huelva and S’Urachi with modern cultivars. Although the pips from S’Urachi are closest to those
 350 of “Albanello”, they do not match the modern cultivars. This is also the case with the ones from
 351 Huelva.

352 The permutational MANOVA carried out to test differences between assemblages was comprised
 353 of a pairwise comparison of modern varieties (both charred and uncharred) and archaeological
 354 samples. In pairwise comparisons, p-values lower than 0.05, which indicate differences in the
 355 pairwise comparison, were seen for: “Albanello” and Huelva; “Coda di Volpe” and Motya
 356 US2268; “Ogialesci”, S’Urachi and Motya US1407; “Perricone”, Motya US1407 and US2268;
 357 “Zerdagi”, Motya US1492 and US2268.

358 Finally, average scores for samples from Motya were plotted on the PCA previously obtained for
 359 the experimentally charred modern cultivars (Fig. 8). This shows that the samples from Motya are
 360 relatively distant from modern cultivars. Even so, the pips from US 1407 and US 7234 are most
 361 similar to “Perricone”, while the mean score for US 1492 falls between “Perricone” and
 362 “Catarratto”, US 2268 is closest to “Zibibbo”, and the pips from US 1112 and US 1406 are finally
 363 closest to “Chichvi”.



364
 365 *Figure 6.* a) PCA of waterlogged archaeological seeds and modern uncharred cultivars (PCA_{water}); b) PCA of charred
 366 grape pips from Motya and modern reference cultivars experimentally charred (PCA_{char}).

367

368 4. Discussion

369 The present study represents a first attempt to evaluate differences in assemblages of grape pips
 370 from Phoenician sites and sites that underwent Phoenician influence. Here we show that: a) there
 371 is a correlation between the geographical origin of modern cultivars and the shape of their pips; b)
 372 the results of the charring experiments are coherent with the existing literature; c) a comparison
 373 between modern and archaeological pips allows the identification of the sites with the most and
 374 least “domesticated” pips; d) no direct match with modern cultivars has been found, even if some
 375 similarities may be noted.

376 In the first place, we have found a correlation between the pip shape of modern cultivars with their
 377 geographical origin, despite a slight overlap of the Sicilian and the Georgian clusters. This
 378 correlation has previously been observed, just as it has also been noted that considering a higher
 379 number of varieties results in less clear-cut differences between geographical groups (Pagnoux et
 380 al., 2015).

381 The results concerning the deformation of pips by charring are consistent with the experiments
 382 conducted by Smith and Jones (1990) and Bouby et al. (2018) and show that the grapevine seeds
 383 become rounder when charred. The stalk is less affected by deformations, at least in its length.
 384 Charring also affects the lateral side by decreasing its curvature.

385 PCA_{archeo} carried out on archaeological pips allows a first comparison of their morphology.
 386 Although slight differences were seen in the roundness of the pips, with those from Huelva and
 387 Motya’s US 1407 being the slimmest, and those from three stratigraphic units in Motya being the

388 roundest, most differences concerned the straightness of the lateral outline and may be ascribed to
389 charring.

390 A more appropriate comparison of archaeobotanical samples was carried out indirectly, by
391 projecting waterlogged pips on PCA_{geo} and charred ones on PCA_{exper}.

392 The comparison between waterlogged seeds from Huelva and S'Urachi highlighted differences
393 rather than similarities. On average, pips from the former site were slimmer and their lateral outline
394 was less curved, in comparison to the ones coming from the Sardinian excavation. At the site of
395 Sa Osa, which is only 10 km from S'Urachi, *Vitis vinifera* remains were found in levels dating to
396 the 13th century BC (Orrù et al., 2013), suggesting an earlier tradition of vine cultivation. This
397 could have been maintained on the island in the following centuries, as suggested by the high
398 concentrations of *Vitis* pollen in the adjacent Mistras lagoon between the middle Bronze Age and
399 the Punic Period (approx. from 3500 to 2500 cal BP; Di Rita and Melis, 2013). In contrast, in the
400 Huelva area grape pips are not present before the 9th-8th centuries.

401 Comparison with modern varieties is not as straightforward. Even if pips from S'Urachi share
402 some features with the modern ones of “Albanello”, “Chichvi”, “Vitrarolo” and “Zibibbo” grapes,
403 no clear correspondence is evident. Even if this lack of conformity may be due to the limited size
404 of the reference collection, we should consider that these are modern varieties, that were quite
405 likely introduced later in history. How closely related can modern and ancient varieties be in a
406 given region? Since grapevines are commonly managed through vegetative propagation it is
407 possible for varieties to remain genetically unchanged for centuries. Nonetheless, new cultivars
408 can be created through sexual crosses or somatic mutations. Ancient DNA studies that may help
409 to trace kinship with modern varieties have been undertaken on archaeological pips from several
410 archaeological sites in France (Ramos-Madrigal et al., 2019). Although a clear match (“Savagnin
411 blanc”) was only found at a medieval site, several pips from Roman sites show first-degree
412 relationships with modern French and Swiss cultivars. This suggests that at least some varieties
413 may remain virtually unchanged since Roman times, and possibly for a longer time.

414 Misidentification can, nonetheless, be influenced by taphonomic factors, including the fact that
415 remains may become slightly swollen because of waterlogging (Pagnoux et al., 2015).

416 The samples from Motya, which have been preserved through charring, differ mostly by their
417 roundness. Pips from the most recent stratigraphic units (US 1112 and US 2268), which make up
418 a single filling layer (Table 2), are the wider ones, with their shape appearing to be of a “least
419 domesticated” type. The expression “least domesticated” refers to the morphology, describing the
420 rounder pips with shortest stalk, closest to the wild morphotype. Similarly, the “most
421 domesticated” pips are the most elongated ones with long stalks. The presence of different
422 morphologies within one filling layer may be related to the fact that these stratigraphic units also
423 included materials from pre-Phoenician layers (such as pottery and other objects), dated back to
424 the 16th-13th century BC. The “least domesticated” pips could therefore have been deposited along
425 with the latter. Pips of units 1407, 1492 and 7234 seem by contrast more elongated and with longer
426 stalks. It is surprising, therefore, that pips from stratigraphic units 1406 and 1407, which also
427 belong to the same depositional layer, differ quite substantially in shape. This may however be due

428 to the small sample size obtained from US 1407. There exists in fact overlap between the datasets,
429 if we examine the values obtained for single pips. The differences may be explained by the
430 presence of different grape varieties within the same depositional layer. A second explanation
431 could be uneven charring in the archaeological context. The context of retrieval is a disposal pit
432 that is several meters wide (Moricca et al., 2021). This would allow for the possibility that higher
433 temperatures were achieved in US 1406 than US 1407, found on the opposite sides of the same
434 filling layer. Charring at higher temperatures has been proven to cause an inflation of the pip bodies
435 (Bouby et al., 2018). Nonetheless, this explanation seems less likely. Such reasoning may also
436 apply to the samples from US 1112 and 2268, even if the values are not as contrasting.

437 In terms of their correspondence to modern cultivars, the outlines of pips from units 1112 and 1406
438 best resemble pips from “Chichvi” grapes, while the seeds from the other samples present shapes
439 noticeably different from the modern reference cultivars. It is interesting in this regard to consider
440 the results of the genetic study carried out by Riaz et al. (2018), who analyzed 1378 cultivated and
441 wild grape samples collected around the Mediterranean basin and Central Asia. While most Italian
442 cultivars clustered with those from France, Spain and Pakistan – Turkmenistan, a small subset was
443 associated with wild and cultivated grapevines from Georgia. This suggests that the first
444 domesticated cultivars in Central Asia and Caucasus (the *proles pontica*) somehow did leave a
445 genetic footprint in the Western European *proles occidentalis*.

446 “Zerdagi” is the modern variety with the broader seeds and least elongated stalks, and which is
447 therefore most like wild grapes, but there are no subfossil equivalents in either the waterlogged or
448 charred assemblages. The same holds for the “Coda di Volpe” variety, which has the slimmest
449 pips and the shortest stalks. These observations may suggest a certain level of domestication of the
450 vine from all the sites studied.

451 Although this reference collection is smaller than those used in other morphometric studies of
452 archaeological grape pips (e.g. Bouby et al., 2021; Pagnoux et al. 2015; Bonhomme et al., 2021),
453 it still encompasses the previously observed archaeological variability.

454 The results of PCA_{water} and PCA_{char} suggest that archaeological material from the three sites is,
455 morphologically, broadly comparable to the modern varieties, which similarly suggests that the
456 archaeological finds represent, broadly speaking, domesticated grapes. If we take into
457 consideration the effects of charring, we note that the “slimmest” pips come from three
458 stratigraphic units at Motya, which may suggest the presence, or perhaps cultivation, of “more
459 strongly domesticated” varieties at or near the Sicilian site.

460 A diversity of cultivated grapes can be observed in the studied sites. This may be ascribed to local
461 adaptation, one hypothesis could be introgression with local grapevines, as suggested by Forni
462 (2012). Another option to consider is that the pips of Motya could be related to the *proles pontica*,
463 which is believed to have left a genetic footprint in the *proles occidentalis* in the Western
464 Mediterranean (Riaz et al., 2018). This might explain differences between the samples from Motya
465 and those from the indigenous sites of S’Urachi and Huelva.

466 Sicilian viticulture is structured by a group of varieties of regional interest, and a bigger group of
467 minor varieties present with a certain frequency only in specific viticultural areas or at the level of

468 a few strains. The latter are referred to as “reliquia” and include “Inzolia” and “Vitarolo” (Scienza
469 and Failla, 2016). Genetic studies have identified the variety “Sangiovese”, as the progenitor of
470 numerous Sicilian cultivars, amongst which “Perricone”. Furthermore, multivariate statistical
471 analyses carried out on 11 SSR loci of 46 Sicilian varieties have shown a clear distinction between
472 varieties based on their geographical origin, with Eastern Sicilian cultivars (“Nerello mascalese”,
473 “Nerello cappuccino”, “Frappato”, “Perricone” and “Carricante”) clustering on one side, and those
474 typical of western Sicily (“Inzolia”, “Catarratto”, “Grecanico”, “Nero d’Avola”) on the other (De
475 Lorenzis et al., 2014).

476 A correspondence between our morphometric results and the ampelographic history of Sicily is
477 not straightforward, either. Even so, pips from S’Urachi find morphological similarities with those
478 of “Albanello”, while three samples from Motya are plotted in the space between “Catarratto” and
479 “Perricone”. It is however unclear how we may interpret such associations.

480 The substantial intra-site diversity in pip morphology at Motya should also be noted, as the sample
481 would seem to cover a range of different varieties. Taphonomic factors, such as differential
482 charring, may however have affected pip morphology. At all the sites the morphology of the pips
483 suggests fully domesticated grapes. The clear differences between pip morphology at the three
484 sites goes against the idea that Phoenicians favoured the spread of grape varieties. It appears more
485 likely that their viticulture was based on local grape varieties, and thus varied with the sites where
486 they settled.

487 The first evidence of viticulture in the Central and Western Mediterranean comes from Northern
488 Italy (Cremaschi et al., 2016; Pecci et al., 2020) and Sardinia (Sabato et al., 2015) and has been
489 dated to the Middle and Late Bronze Age (ca. 1650-930 BC). It does not, however, point to the
490 exclusive use of domesticated varieties. There is little or no evidence to assess the continuity, scale
491 and prominence of viticulture in the western Mediterranean during the later 2nd millennium BC,
492 but that changes by the beginning of the 1st millennium with new finds from Tunisia, Sicily,
493 Sardinia and the Iberian Peninsula, which may be associated with a Phoenician presence. The rapid
494 growth of vine cultivation and wine production in the first half of the new millennium generated
495 increasingly frequent exchanges of wine amphorae across the Western Mediterranean (Botto,
496 2013). Vine cultivation and wine production also became widespread in indigenous areas, where
497 amphora production and wine presses have been found (Pérez-Jordà et al., 2013). Thanks to the
498 Orientalizing influence, which includes not only Phoenicians, but also Greeks and Etruscans, wine
499 soon became a very successful and widely distributed product with substantial agricultural,
500 economic and cultural impact and significance (Botto, 2013). This underscores the interest of
501 trying to define in precise terms the history, distribution, expansion and cultural appreciation of
502 this crop. The varieties that were introduced and/or created in each of the areas are an essential
503 element of this historical process, which indicates the relevance of the line of research that is
504 opened with this work.

505 **5. Conclusions**

506 The present study has first of all allowed us to characterize the pip morphology of grapes cultivated
507 by Phoenicians and connected indigenous communities in the West Mediterranean and to assess
508 the similarities and difference between these ancient seeds and modern varieties using geometric
509 morphometry. We first of all observed that all the studied archaeological grape pip samples fall
510 within the range defined by the modern cultivars, which is reason to describe our archaeological
511 samples as ‘domesticated-looking’. Taking in consideration the effects of charring on pip shape,
512 pips from three stratigraphic units at Motya (1407, 1492 and 1407) appear to be the slimmest.
513 More specifically, pips from stratigraphic unit 1407 are the most elongated, closely followed by
514 those from units 1492 and 7234. Although it was not possible to associate them with any specific
515 modern variety, they broadly resemble the Sicilian cultivars “Perricone” and “Catarratto”. In terms
516 of elongation, these are closely followed by pips from Huelva, which do not resemble any of the
517 reference cultivars. The remaining pips from S’Urachi and Motya (US 2268, 1406 and 1112) are
518 rounder.

519 None of the pips investigated resembles those of the Georgian cultivar “Zerdagi”, which has the
520 roundest pips among the selected modern cultivars.

521 The key challenge for the present study was the comparison of archaeological pips preserved
522 through different fossilization processes (waterlogging and charring). Although it is impossible to
523 undo the charring conditions that created the archaeobotanical assemblage, experimental charring
524 has been used to obtain material that may be compared to well-preserved archaeobotanical
525 material. The use of two reference datasets of the same modern cultivars, one uncharred and one
526 charred, has enabled us to tackle the complications of differential preservation.

527 Our analysis represents a first step towards a better understanding of diachronic and synchronic
528 relationship between vines grown in the ancient West Mediterranean. We are well aware that the
529 small number of reference cultivars used in this study may not adequately represent the diversity
530 of modern grapevine cultivars. Even so, our selection still offers a general impression of modern
531 similarities with the archaeological samples, which supports our suggestion that local cultivation
532 and selection could have produced important changes and long-term consequences.

533 We recommend that future studies be carried out with a larger number of modern reference
534 cultivars that better represent contemporary biological diversity. An additional focus could be
535 placed on modern Sardinian and Iberian cultivars. If the number of samples from each
536 archaeological site could also be increased, we would also gain a better understanding of grape
537 diversity at each site. Even so, finds from other sites would likely be necessary to take a broader
538 view and to evaluate the role of Phoenicians in the diffusion of the grapevine across the western
539 Mediterranean.

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551

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558

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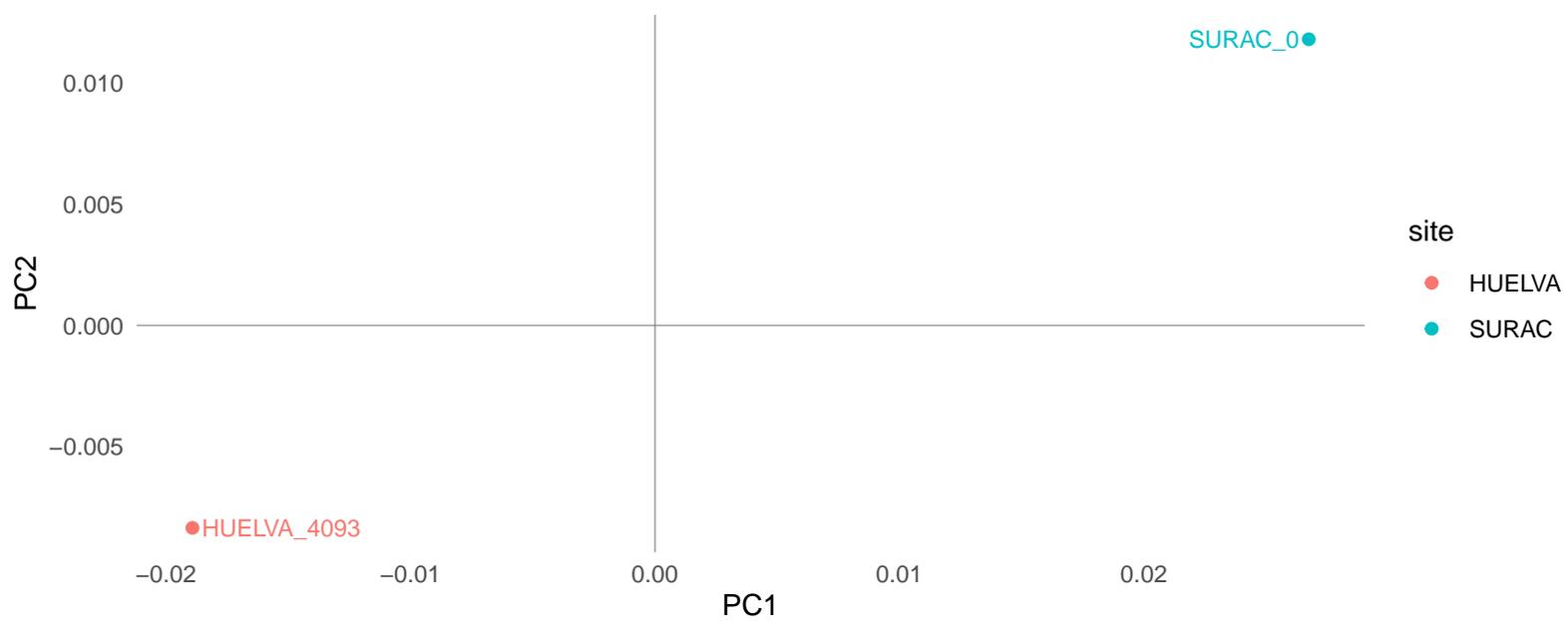
823 **Supplementary materials**

824 *Supplementary material 1.* PCA of waterlogged archaeological samples.

825 *Supplementary material 2.* PCA of charred archaeological samples.

Supplementary Material 1

Archaeological waterlogged PCA



Supplementary Material 2

